



**UNIVERSITI PUTRA MALAYSIA**

**STRUCTURE, MICROSTRUCTURE AND SUPERCONDUCTIVITY OF  
YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub>- WITH MAGNETIC NANOPARTICLE ADDITIVES**

**MOHD KAMARULZAMAN BIN MANSOR**

**FS 2010 6**





**STRUCTURE, MICROSTRUCTURE AND  
SUPERCONDUCTIVITY OF  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  WITH  
MAGNETIC NANOPARTICLE ADDITIVES**

**MOHD KAMARULZAMAN BIN MANSOR**

**MASTER OF SCIENCE  
UNIVERSITI PUTRA MALAYSIA**

**2010**





**STRUCTURE, MICROSTRUCTURE AND SUPERCONDUCTIVITY OF  
 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  WITH MAGNETIC NANOPARTICLE ADDITIVES**

**By**

**MOHD KAMARULZAMAN BIN MANSOR**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Master Science**

**February 2010**



## **DEDICATION**

*To my mom and dad who love me so much*

**MALINI BINTI HUSSIN  
MANSOR BIN AHMAD**

*Beloved wife*

**HASNIDAR BINTI HAMID**

*Son*

**MUHAMMAD FATHI BIN MOHD KAMARULZAMAN**

*Sisters*

**NORSURIANI BINTI MANSOR  
NORHAFIZZAH BINTI MANSOR**

*Nephews*

**AMIR HARITH IMTIYAZ  
AFEEF HAZMAN IMTIYAZ**

Abstract of thesis presented to Senate of Universiti Putra Malaysia in fulfilment  
of the requirement for the degree of Master of Science

**STRUCTURE, MICROSTRUCTURE AND SUPERCONDUCTIVITY OF  
YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-δ</sub> WITH MAGNETIC NANOPARTICLE ADDITIVES**

By

**MOHD KAMARULZAMAN BIN MANSOR**

**February 2010**

**Chairman: Professor Abdul Halim Shaari, PhD**

**Faculty: Science**

Potential enhancement of flux pinning by rare-earth (RE) magnetic nanoparticles added into bulk of YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-δ</sub> (YBCO) was studied experimentally. In particular, a comprehensive investigation of crystal structure, microstructure and superconducting properties of YBCO added with  $x$  weight percent ( $x = 0.0 - 0.6$  wt. %) of nanosized ( $\leq 25$  nm) Nd<sub>2</sub>O<sub>3</sub>, Sm<sub>2</sub>O<sub>3</sub>, Gd<sub>2</sub>O<sub>3</sub> and Yb<sub>2</sub>O<sub>3</sub> prepared via solid state technique was presented. X-ray diffraction (XRD) technique was used for crystal structure and phase formation identification. Detailed crystal structure analysis was carried out on each sample using the Rietveld refinement technique. The fractured cross section microstructure was observed using Scanning Electron Microscopy (SEM) and support by elemental analysis using Energy Dispersive X-ray (EDX) spectroscopy. Four point probe technique were employed to study the resistance dependence from room temperature down to 50 K.

The XRD patterns revealed that only YBCO phase peaks were observed for sample with  $x \leq 0.3$  and minor intensities of 211 secondary phase was observed for  $x \geq 0.4$  in each

series. The XRD patterns of all samples were indexed in the orthorhombic structure with space group  $Pmmm$ . All refined  $R_{wp}$  factor values are in between 9 % - 12 % different, which support the refined structure model reasonably and reflected that the refined curve fit well with the measured ones. Refinement of the XRD patterns indicated that magnetic nanoparticles added changed the lattice constants of the unit cell due to the rare-earth (RE) ionic radius and their replacement sites.  $RE^{3+}$  was found to incorporate into the crystal structure and could replace either the Y-site or Ba-site. The size of the lattice mismatch created between non-substituted and substituted unit cell was comparable to the size of the vortex core which may provide a potential flux pinning sites.

Surface microstructure study showed the grain size, grain boundary and porosity of the each series was significantly influenced by the concentration of additives. Grain size in each series become smaller from low to high concentration and the mixture between rectangular plate-like and granular grains was observed. The change in microstructure significantly influenced the absolute value of resistance in the normal state. EDX analysis showed a typical YBCO energy spectrum together with added element in the samples. The energy spectrum corresponding to the added elements become more prominent as  $x$  increased confirming that  $RE^{3+}$  was actually incorporated into the system.

The metallic behavior in the normal state of samples added with  $Gd_2O_3$  and  $Yb_2O_3$  was maintained until higher value of  $x$  added. However, the normal state behavior changes from metallic to semiconducting when the concentration of  $Nd_2O_3$  and  $Sm_2O_3$  increased. With the increase of additive concentration, the superconducting transition temperature

decreased from 92 K to a lower value depending on the type of additives and the weight percent added. The depression of  $T_{c-zero}$  value has been attributed by the variation of the mobile carrier density in the  $CuO_2$  plane and various structure changes. It may also be due to the Cooper pair breaking caused by the  $RE^{3+}$  which partially substituted at Y-site and Ba-site in crystal structure.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**STRUKTUR, MIKROSTRUKTUR DAN KESUPERKONDUKSIAN  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$   
DENGAN ADITIF ZARAH NANO BERMAGNET**

Oleh

**MOHD KAMARULZAMAN BIN MANSOR**

**Februari 2010**

**Pengerusi: Professor Abdul Halim Shaari, PhD**

**Fakulti: Sains**

Potensi peningkatan pusat pengepitan fluks oleh bahan magnet nadir bumi berzarah nano ditambah dalam  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  (YBCO) telah dikaji secara eksperimen. Secara khusus, penyelidikan secara meluas terhadap struktur kristal, mikrostruktur dan sifat superkonduktor YBCO pukal ditambah dengan  $x$  peratus berat ( $x = 0.0 - 0.6$  peratus berat)  $\text{Nd}_2\text{O}_3$ ,  $\text{Sm}_2\text{O}_3$ ,  $\text{Gd}_2\text{O}_3$  dan  $\text{Yb}_2\text{O}_3$  bersaiz nano ( $\leq 25$  nm) yang disediakan melalui teknik keadaan pepejal telah ditunjukkan. Teknik pembelauan sinar-X telah digunakan untuk mengenalpasti struktur hablur dan juga fasa yang terbentuk. Analisis secara mendalam telah dijalankan terhadap semua sampel dengan menggunakan teknik pemurnian Rietveld. Mikrostruktur patahan keratan rentas telah dilihat dengan menggunakan Mikroskop Pengimbas Elektron dan disokong oleh analisis unsur dengan menggunakan spektroskopi Penyerakan Tenaga Sinar-X. Penduga empat titik digunakan untuk mengkaji perubahan rintangan terhadap suhu dari suhu bilik kepada 50 K.



Corak pembelauan sinar-X menunjukkan fasa tunggal YBCO bagi sampel dengan  $x \leq 0.3$  dan fasa sekunder 211 minor dapat dilihat bagi  $x \geq 0.4$  bagi setiap siri. Corak pembelauan sinar-X dapat diindekskan dalam struktur ortorombik dengan kumpulan ruang *Pmmm*. Semua nilai faktor  $R_{wp}$  adalah antara 9 % - 12 %, yang menyokong model struktur permurnian secara munasabah dan membayangkan bahawa lengkungan termurni adalah sepadan dengan yang telah dikira. Pemurnian corak pembelauan sinar-X menunjukkan bahawa nano zarah yang ditambah telah mengubah pemalar kekisi dalam sel unit bergantung terhadap jajari ion  $RE^{3+}$  dan tapak penggantian.  $RE^{3+}$  di dapati masuk ke dalam struktur hablur dan boleh menggantikan sama ada tapak-Y atau tapak-Ba. Saiz ketidak sepadanan yang terbentuk antara sel unit yang terganti dan tidak terganti adalah sebanding dengan teras pusat dan ianya menyediakan tapak yang berpotensi sebagai pusat pengepinan fluks.

Kajian mikrostruktur permukaan menunjukkan bahawa saiz butiran, sempadan antara butiran dan keadaan berliang dalam setiap siri terpengaruh oleh jumlah aditif. Saiz butiran dalam setiap siri menjadi semakin kecil daripada jumlah aditif yang rendah kepada jumlah aditif yang tinggi dan campuran antara kepingan seperti segi empat tepat dan butiran dapat diperhatikan. Perubahan dalam mikrostruktur telah mempengaruhi nilai sebenar rintangan pada keadaan normal. Analisis Penyerakan Tenaga Sinar-X menunjukkan spektrum tenaga yang lazim bagi YBCO bersama unsur aditif dalam setiap sampel. Spektrum tenaga yang sepadan dengan unsur aditif menjadi lebih menonjol apabila nilai  $x$  meningkat dan mengesahkan bahawa  $RE^{3+}$  sebenarnya masuk ke dalam sistem hablur.

Sifat metalik pada keadaan normal bagi sampel yang ditambah dengan  $\text{Gd}_2\text{O}_3$  dan  $\text{Yb}_2\text{O}_3$  adalah kekal sehingga nilai tertinggi. Walau bagaimanapun sifat pada keadaan normal berubah daripada sifat metalik kepada semikonduksian apabila jumlah  $\text{Nd}_2\text{O}_3$  dan  $\text{Sm}_2\text{O}_3$  meningkat. Dengan penambahan jumlah bahan aditif, nilai suhu peralihan berkurangan daripada 92 K kepada nilai yang lebih rendah bergantung kepada jenis aditif dan peratus berat yang ditambah. Penurunan pada nilai  $T_{\text{c-zero}}$  adalah disebabkan oleh perubahan kepadatan mobil pembawa dalam satah  $\text{CuO}_2$  dan kepelbagaian perubahan struktur. Ianya juga mungkin disebabkan oleh pemisahan pasangan Cooper oleh  $\text{RE}^{3+}$  yang telah terganti secara separa pada tapak-Y dan tapak-Ba dalam struktur hablur.

## ACKNOWLEDGEMENTS

First and foremost, I would like to extend my deepest praise to Allah s.w.t that has given me patience, strength, determination and courage to complete this research. I would like to express my utmost gratitude to Prof. Dr. Abdul Halim Shaari, Dr. Cheen Soo Kien and Dr. Malik Idries Adam for their constant monitoring, support, encouragement and sponsoring during period of this research. Working with them has provided me with vast understanding on materials science and theoretical knowledge from which I will continue to draw benefit in the future.

I am grateful to my group members Mohd Faisal Mohd Aris, Dr. Walter Charles Primus, Dr. Kong Wei and all my laboratory colleague for their tremendous assistance and support throughout this study. I am also grateful to Madam Yasmin and Mr. Rafi from SEM unit in Institute Biosains (IBS) for their guidance and assistance.

Finally, I would like to express my fullest appreciation to my parents for being so understanding. To my mom and my wife, I love both of you so much.

*M. Kamarulzaman*

I certify that a Thesis Examination Committee has met on 23 February 2010 to conduct the final examination of Mohd. Kamarulzaman Bin Mansor on his thesis entitled “Structure, Microstructure and Superconductivity of  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  with Magnetic Nanoparticle Additives” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master.

Members of The Thesis Examination Committee were as follows:

**Zulkifli Abas, PhD**

Faculty of Science  
Universiti Putra Malaysia  
(Chairman)

**Zainal Abidin Talib, PhD**

Associate Professor  
Faculty of Science  
Universiti Putra Malaysia  
(Internal Examiner)

**Kamirul Amin Matori, PhD**

Faculty of Science  
Universiti Putra Malaysia  
(Internal Examiner)

**Roslan Ab. Shukor, PhD**

Professor  
School of Applied Physics  
Universiti Kebangsaan Malaysia  
Malaysia  
(External Examiner)

---

**BUJANG BIN KIM HUAT, PhD**

Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master. The members of the Supervisory Committee were as follows:

**Abdul Halim Shaari, PhD**

Professor  
Faculty of Science  
Universiti Putra Malaysia  
(Chairman)

**Chen Soo Kien, PhD**

Faculty of Science  
Universiti Putra Malaysia  
(Member)

---

**HASANAH MOHD GHAZALI, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 13 May 2010

## **DECLARATION**

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

---

**MOHD KAMARULZAMAN BIN MANSOR**

Date: 23 February 2010

## TABLE OF CONTENTS

	Page
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	vi
<b>ACKNOWLEDGEMENTS</b>	ix
<b>APPROVAL</b>	x
<b>DECLARATION</b>	xii
<b>LIST OF TABLES</b>	xv
<b>LIST OF FIGURES</b>	xvi
<b>LIST OF PLATES</b>	xix
<b>LIST OF ABBREVIATIONS</b>	xxi
 <b>CHAPTER</b>	
 1 <b>INTRODUCTION</b>	 1
1.1    Introduction	1
1.2    Objectives of the Study	5
1.3    Scope of the Study	5
1.4    Overview of the Thesis	6
 2 <b>LITERATURE REVIEW</b>	 7
2.1    Rare-earth Doping and Adding in YBCO	7
2.2    Nd, Sm Gd and Yb Adding and Doping in YBCO	9
2.3    Adding and Doping in Other Cuprate System	10
 3 <b>THEORY</b>	 13
3.1    Structure of YBCO	13
3.2    Rare-earth Substitutions or Additions on YBCO	14
3.3    Magnetic Pinning Center	16
3.4    Nanosize Pinning Centers	16
3.5    Rietveld Refinement	17
3.6    Theoretical Basis of Superconductivity	19
3.7    Vortex Matter	24
3.8    Vortex Motion	25
3.9    Vortex Pinning	26
3.10   Mechanisms of Vortex Pinning	27
 4 <b>MATERIALS AND METHODS</b>	 29
4.1    Sample Preparation	29
4.2    Characterization Methods	33
4.2.1   X-ray Diffraction (XRD) and Crystal Structure Analysis	34



	4.2.2	Microstructure Analysis	35
	4.2.3	Elemental Analysis	36
	4.2.4	DC Electrical Resistance Measurement	36
	4.3	Experimental Errors	38
5		<b>RESULTS AND DISCUSSION</b>	39
	5.1	Introduction	39
	5.2	X-Ray Diffraction and Crystal Structure Analysis	39
	5.3	Microstructure Analysis	60
	5.3.1	Microstructure Analysis of Pure YBCO	60
	5.3.2	Microstructure Analysis of Samples with Additives	62
	5.4	Elemental Analysis	79
	5.5	DC Electrical Resistance Measurement	82
	5.5.1	Resistance Dependence of Temperature of pure YBCO	82
	5.5.2	Resistance Dependence of Temperature of YBCO + $x$ wt. % of $\text{Nd}_2\text{O}_3$	83
	5.5.3	Resistance Dependence of Temperature of YBCO + $x$ wt. % of $\text{Sm}_2\text{O}_3$	87
	5.5.4	Resistance Dependence on Temperature of YBCO + $x$ wt. % of $\text{Gd}_2\text{O}_3$	90
	5.5.5	Resistance Dependence on Temperature of YBCO + $x$ wt. % of $\text{Yb}_2\text{O}_3$	93
6		<b>CONCLUSION AND SUGGESTIONS FOR FUTURE STUDY</b>	98
	6.1	Conclusion	98
	6.2	Suggestions	101
		<b>REFERENCES</b>	103
		<b>APPENDIX A</b>	109
		<b>BIODATA OF STUDENT</b>	113



## LIST OF TABLES

Table		Page
4.1	Crystallographic information data of Rietveld refinement of YBCO	35
5.1	Refined lattice parameters and R-factor values for YBCO added with various amounts of $\text{Nd}_2\text{O}_3$	49
5.2	Refined lattice parameters and R-factor values for YBCO added with various amounts of $\text{Sm}_2\text{O}_3$	52
5.3	Refined lattice parameters and R-factor values for YBCO added with various amounts of $\text{Gd}_2\text{O}_3$	54
5.4	Refined lattice parameters and R-factor values for YBCO added with various amounts of $\text{Yb}_2\text{O}_3$	57
5.5	The resistance dependence of temperature relationship for samples added with various amounts of $\text{Nd}_2\text{O}_3$	86
5.6	The resistance dependence of temperature relationship for samples added with various amounts of $\text{Sm}_2\text{O}_3$	89
5.7	The resistance dependence of temperature relationship for samples added with various amounts of $\text{Gd}_2\text{O}_3$	93
5.8	The resistance dependence of temperature relationship for samples added with various amounts of $\text{Yb}_2\text{O}_3$	96

## LIST OF FIGURES

Figure		Page
3.1	Schematic of the crystalline structure of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$	13
3.2	Electrical resistance versus temperature of a superconductor	20
3.3	Magnetic field dependence of magnetization for type-I superconductor	22
3.4	Meissner Effect	22
3.5	Magnetic field dependence of magnetization for type-II superconductor	23
3.6	Superconductivity critical values $T_c$ , $J_c$ and $H_c$	24
3.7	Vortices subjected to the Lorentz force	25
4.1	Schematic drawing of the sample preparation and characterization process	30
4.2	The heat treatment profile used in the sample preparation process. (a) calcination and (b) sintering	33
4.3	Basic setup of the four point probe system	37
5.1	X-ray diffraction pattern for pure YBCO sample	40
5.2	X-ray powder diffraction patterns of YBCO samples added with various amounts of $\text{Nd}_2\text{O}_3$	42
5.3	X-ray powder diffraction patterns of YBCO samples added with various amounts of $\text{Sm}_2\text{O}_3$	43
5.4	X-ray powder diffraction patterns of YBCO samples added with various amounts of $\text{Gd}_2\text{O}_3$	44
5.5	X-ray powder diffraction patterns of YBCO samples added with various amounts of $\text{Yb}_2\text{O}_3$	45
5.6	Variation in intensity and position of (013) and (103) peaks for YBCO added with various amounts of (a) $\text{Nd}_2\text{O}_3$ , (b) $\text{Sm}_2\text{O}_3$ , (c) $\text{Gd}_2\text{O}_3$ and (d) $\text{Yb}_2\text{O}_3$ respectively	47

5.7	Rietveld refinement profile of pure YBCO sample	48
5.8	Variation of lattice constants along $a$ -, $b$ -, $c$ -axis and $V$ for YBCO added with various amounts of $\text{Nd}_2\text{O}_3$	50
5.9	Variation of lattice constants along $a$ -, $b$ -, $c$ -axis and $V$ for YBCO added with various amounts of $\text{Sm}_2\text{O}_3$	53
5.10	Variation of lattice constants along $a$ -, $b$ -, $c$ -axis and $V$ for YBCO added with various amounts of $\text{Gd}_2\text{O}_3$	55
5.11	Variation of lattice constants along $a$ -, $b$ -, $c$ -axis and $V$ for YBCO added with various amounts of $\text{Yb}_2\text{O}_3$	58
5.12	Surface of YBCO + 0.2 wt. % $\text{Nd}_2\text{O}_3$ sample with ten selected spots area randomly	79
5.13	EDX spectrum of pure YBCO sample	80
5.14	EDX spectrum of YBCO + 0.6 wt. % of $\text{Nd}_2\text{O}_3$	80
5.15	EDX spectrum of YBCO + 0.3 wt. % of $\text{Sm}_2\text{O}_3$	81
5.16	EDX spectrum of YBCO + 0.5 wt. % of $\text{Gd}_2\text{O}_3$	81
5.17	EDX spectrum of YBCO + 0.2 wt. % of $\text{Yb}_2\text{O}_3$	81
5.18	The resistance dependence of temperature for the pure YBCO sample. Inset shows the transition step taken	83
5.19	The resistance dependence of temperature for samples added with various amounts of $\text{Nd}_2\text{O}_3$	85
5.20	The variation of the superconducting transition temperature, $T_{c\text{-onset}}$ and $T_{c\text{-zero}}$ dependence of the content of $\text{Nd}_2\text{O}_3$ . Inset shows transition step of each samples	87
5.21	The resistance dependence of temperature for samples sintered with various amounts of $\text{Sm}_2\text{O}_3$	88
5.22	The variation of the superconducting transition temperature, $T_{c\text{-onset}}$ and $T_{c\text{-zero}}$ dependence of the content of $\text{Sm}_2\text{O}_3$ . Inset shows transition step of each samples	90
5.23	The resistance dependence of temperature for samples added with various amounts of $\text{Gd}_2\text{O}_3$	91

5.24	The variation of the superconducting transition temperature, $T_{c-Onset}$ and $T_{c-zero}$ dependence of the content of $Gd_2O_3$ . Inset shows transition step of each samples	93
5.25	The resistance dependence of temperature for samples added with various amounts of $Yb_2O_3$	95
5.26	The variation of the superconducting transition temperature, $T_{c-Onset}$ and $T_{c-zero}$ dependence of the content of $Yb_2O_3$ . Inset shows transition step of each samples	97
A.1	Rietveld refinement profile of $YBCO + x$ wt % of $Nd_2O_3$ . (a) $x = 0.1$ , (b) $x = 0.2$ , (c) $x = 0.3$ , (d) $x = 0.4$ , (e) $x = 0.5$ and (f) $x = 0.6$	109
A.2	Rietveld refinement profile of $YBCO + x$ wt % of $Sm_2O_3$ . (a) $x = 0.1$ , (b) $x = 0.2$ , (c) $x = 0.3$ , (d) $x = 0.4$ , (e) $x = 0.5$ and (f) $x = 0.6$	110
A.3	Rietveld refinement profile of $YBCO + x$ wt % of $Gd_2O_3$ . (a) $x = 0.1$ , (b) $x = 0.2$ , (c) $x = 0.3$ , (d) $x = 0.4$ , (e) $x = 0.5$ and (f) $x = 0.6$	111
A.4	Rietveld refinement profile of $YBCO + x$ wt % of $Yb_2O_3$ . (a) $x = 0.1$ , (b) $x = 0.2$ , (c) $x = 0.3$ , (d) $x = 0.4$ , (e) $x = 0.5$ and (f) $x = 0.6$	112

## LIST OF PLATES

Plate		Page
4.1	TEM images of each type of nanoparticle. (a) $\text{Nd}_2\text{O}_3$ , (b) $\text{Sm}_2\text{O}_3$ , (c) $\text{Gd}_2\text{O}_3$ and (d) $\text{Yb}_2\text{O}_3$	31
5.1	SEM micrograph of pure YBCO sample at 1000X	61
5.2	SEM micrograph of pure YBCO sample at 5000X	61
5.3	SEM micrograph of YBCO + 0.1 wt. % $\text{Nd}_2\text{O}_3$	66
5.4	SEM micrograph of YBCO + 0.2 wt. % $\text{Nd}_2\text{O}_3$	66
5.5	SEM micrograph of YBCO + 0.3 wt. % $\text{Nd}_2\text{O}_3$	67
5.6	SEM micrograph of YBCO + 0.4 wt. % $\text{Nd}_2\text{O}_3$	67
5.7	SEM micrograph of YBCO + 0.5 wt. % $\text{Nd}_2\text{O}_3$	68
5.8	SEM micrograph of YBCO + 0.6 wt. % $\text{Nd}_2\text{O}_3$	68
5.9	SEM micrograph of YBCO + $x$ wt. % of $\text{Nd}_2\text{O}_3$ samples: (a) $x = 0.1$ (b) $x = 0.6$	69
5.10	SEM micrograph of YBCO + 0.1 wt. % $\text{Sm}_2\text{O}_3$	69
5.11	SEM micrograph of YBCO + 0.2 wt. % $\text{Sm}_2\text{O}_3$	70
5.12	SEM micrograph of YBCO + 0.3 wt. % $\text{Sm}_2\text{O}_3$	70
5.13	SEM micrograph of YBCO + 0.4 wt. % $\text{Sm}_2\text{O}_3$	71
5.14	SEM micrograph of YBCO + 0.5 wt. % $\text{Sm}_2\text{O}_3$	71
5.15	SEM micrograph of YBCO + 0.6 wt. % $\text{Sm}_2\text{O}_3$	72
5.16	SEM micrograph of YBCO + 0.1 wt. % $\text{Gd}_2\text{O}_3$	72
5.17	SEM micrograph of YBCO + 0.2 wt. % $\text{Gd}_2\text{O}_3$	73
5.18	SEM micrograph of YBCO + 0.3 wt. % $\text{Gd}_2\text{O}_3$	73
5.19	SEM micrograph of YBCO + 0.4 wt. % $\text{Gd}_2\text{O}_3$	74

5.20	SEM micrograph of YBCO + 0.5 wt. % $\text{Gd}_2\text{O}_3$	74
5.21	SEM micrograph of YBCO + 0.6 wt. % $\text{Gd}_2\text{O}_3$	75
5.22	SEM micrograph of YBCO + 0.1 wt. % $\text{Yb}_2\text{O}_3$	75
5.23	SEM micrograph of YBCO + 0.2 wt. % $\text{Yb}_2\text{O}_3$	76
5.24	SEM micrograph of YBCO + 0.3 wt. % $\text{Yb}_2\text{O}_3$	76
5.25	SEM micrograph of YBCO + 0.4 wt. % $\text{Yb}_2\text{O}_3$	77
5.26	SEM micrograph of YBCO + 0.5 wt. % $\text{Yb}_2\text{O}_3$	77
5.27	SEM micrograph of YBCO + 0.6 wt. % $\text{Yb}_2\text{O}_3$	78
5.28	SEM micrograph of YBCO + 0.6 wt. % $\text{Yb}_2\text{O}_3$ at 5000X	78

## LIST OF ABBREVIATIONS

YBCO	Yttrium Barium Copper Oxide
YbBCO	Ytterbium Barium Copper Oxide
NdBCO	Neodymium Barium Copper Oxide
Y123	Yttrium Barium Copper Oxide
Pr123	Praseodymium Barium Copper Oxide
REBCO	Rear-earth Barium Cooper Oxide
HTSC	High Temperature Superconductor
XRD	X-ray Diffraction
SEM	Scanning Electron Microscopy
EDX	Energy Dispersion X-ray
TEM	Transmission Electron Microscopy
ZFC	Zero Field Cool
UPM	Universiti Putra Malaysia
PLD	Pulse Laser Deposition
DC	Direct Current
RE	Rare-earth
U.S	United State
1 G	First generation
2 G	Second generation
A	Ampere
I	Current
R	Resistance

V	Voltage
X	Magnification
N	Total number of points
P	Adjusted parameters
C	Number of constrains applied
B	Magnetic Field
H	Magnetic Field
$H_e$	Magnetic field applied
$H_c$	Critical field
M	Magnetization
$H_{c2}$	Upper critical magnetic field
$H_{c1}$	Lower critical magnetic field
$T_c$	Critical temperature
$J_c$	Critical current
$T_s$	Spin gap temperature
$T_{c-Onset}$	Onset critical temperature
$T_{c-zero}$	Zero critical temperature
$T_{c\ max}$	Maximum critical temperature
$\Delta T_c$	Delta critical temperature
wt.	Weight
nm	Nanometer
mm	Millimeter
$\mu m$	Micrometer



$kV$	Kilovolt
$R_{exp}$	Expected R-factor
$R_{wp}$	Weighted pattern R-factor
$R_p$	Profile R-factor
$Y_{oi}$	Observed intensities
$Y_{ci}$	calculated intensities
$\Sigma_i$	Total of steps
$i$	Number of step
$W_i$	Weight
$a$	Lattice parameter
$b$	Lattice parameter
$c$	Lattice parameter
$V$	Unit cell volume
$p$	Hole concentration
$x$	Amount of weight percent added
$\theta$	Theta
$\xi$	Coherence length
$\delta$	Delta
$=$	Equal
$\leq$	Less than or equal to
$\geq$	Greater than or equal to
$>$	Bigger than
$\text{\AA}$	Angstrom Unit